

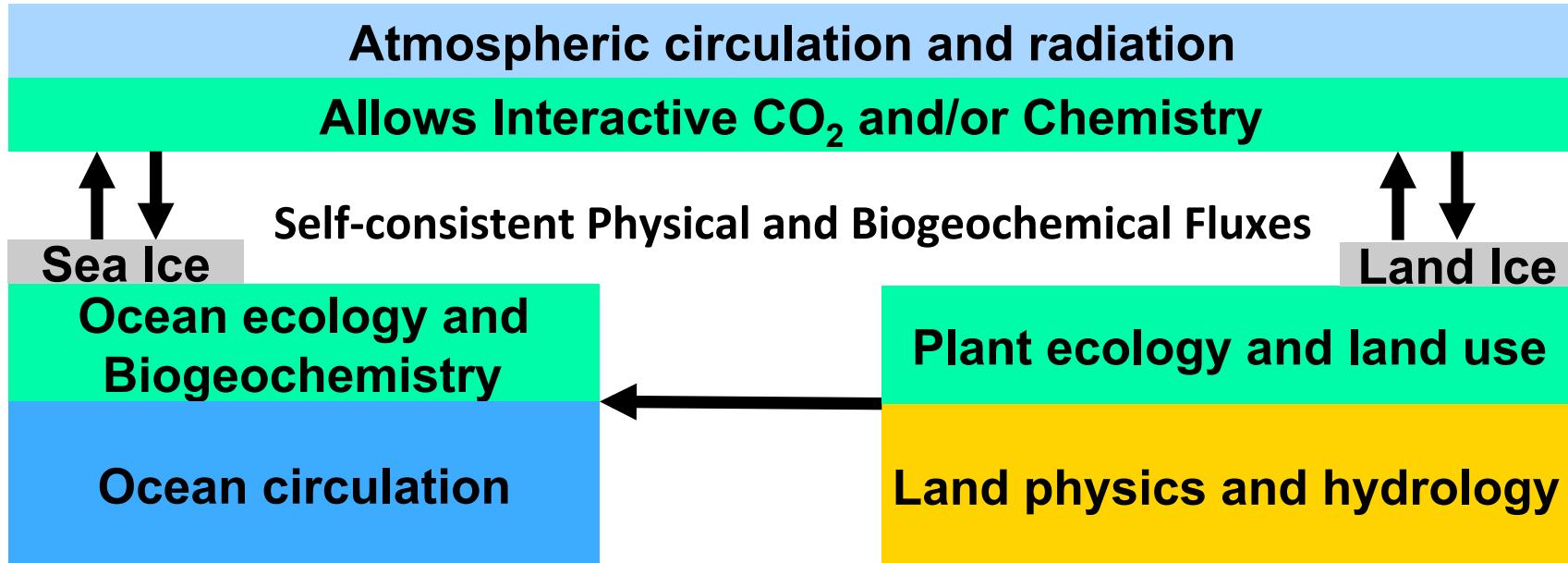
Improving understanding of historical and future terrestrial carbon sinks with the GFDL Earth system models

Elena Shevliakova

Geophysical Fluid Dynamics Laboratory

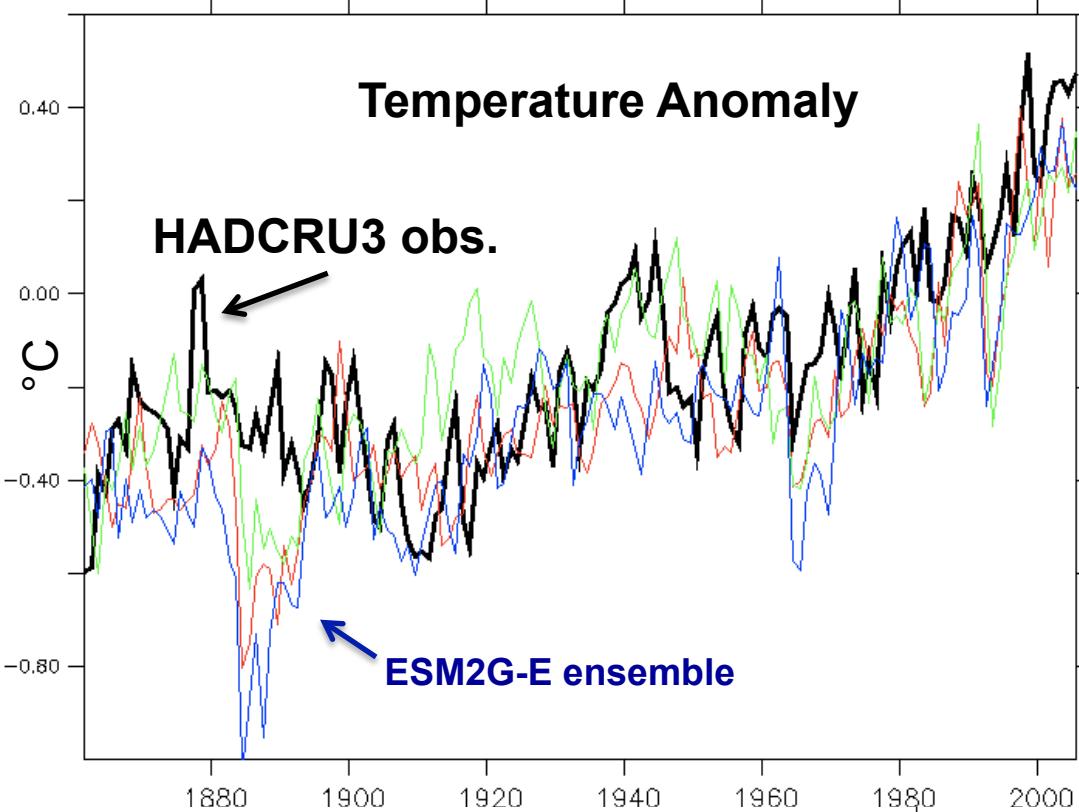


GFDL ESMs for Coupled Carbon-Climate and Chemistry



- ESM2M and ESM2G for CMIP5, (Dunne et al 2012, et al 2013)
- Comprehensive land and ocean carbon dynamics
- Interactive/prognostic or prescribed CO₂
- Two-way coupling for hydrological and BGC exchanges
- Allows investigation of biosphere feedbacks
- Amenable to inter-disciplinary impacts studies

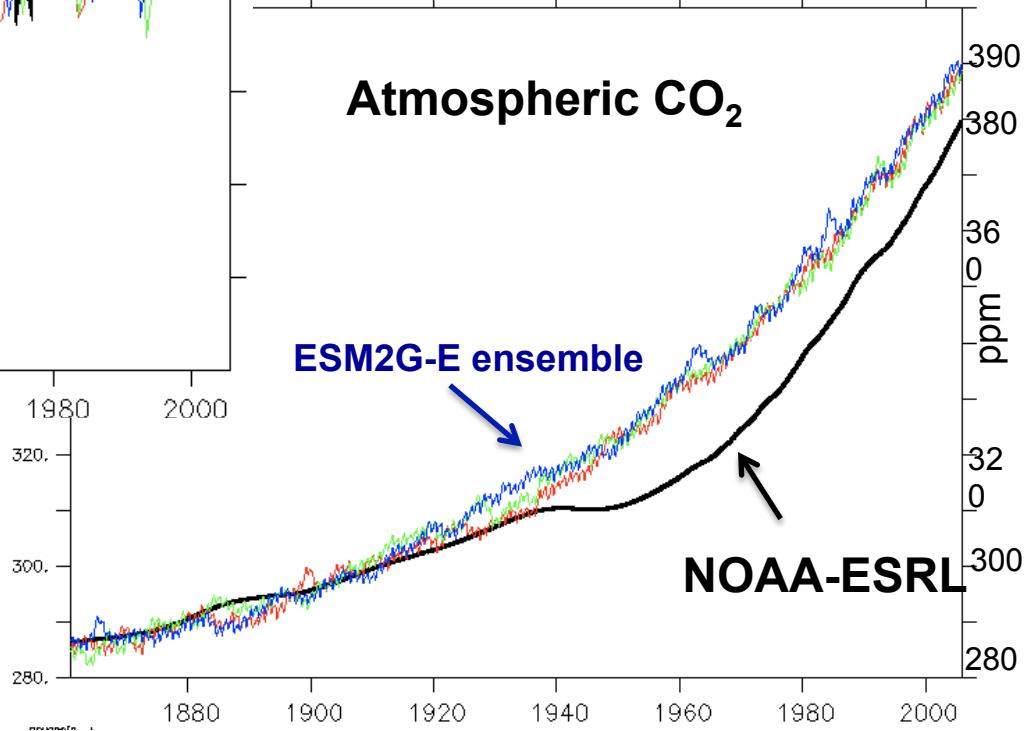
ESM2G captures historical trends



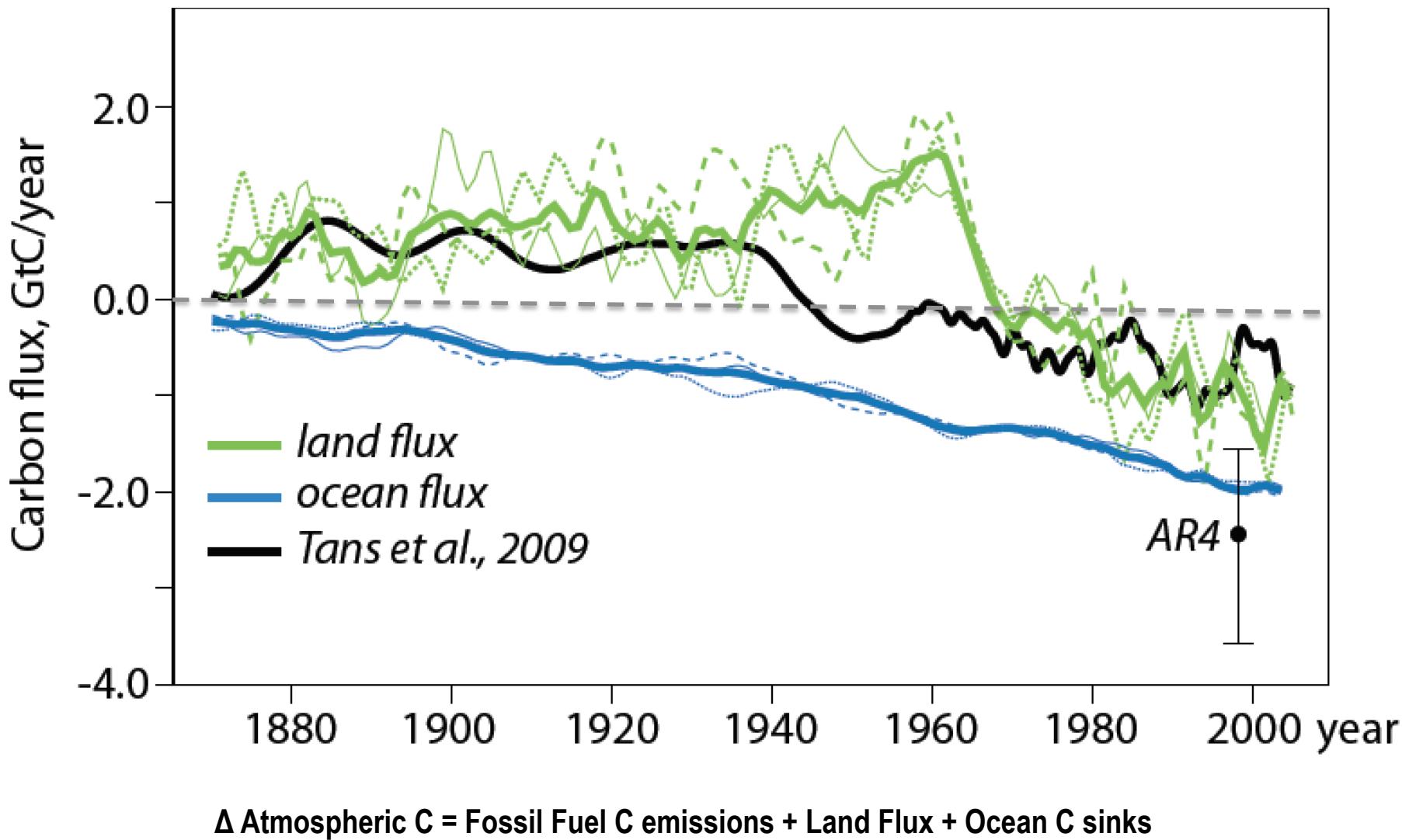
Shevliakova et al 2013

Drivers:

- CO₂ fossil fuel and cement emissions
- Other radiative forcing
- Land-use scenario



ESM2G's terrestrial and ocean sinks trends



Land-use (from CMIP5 reconstruction, Hurt et al 2011)

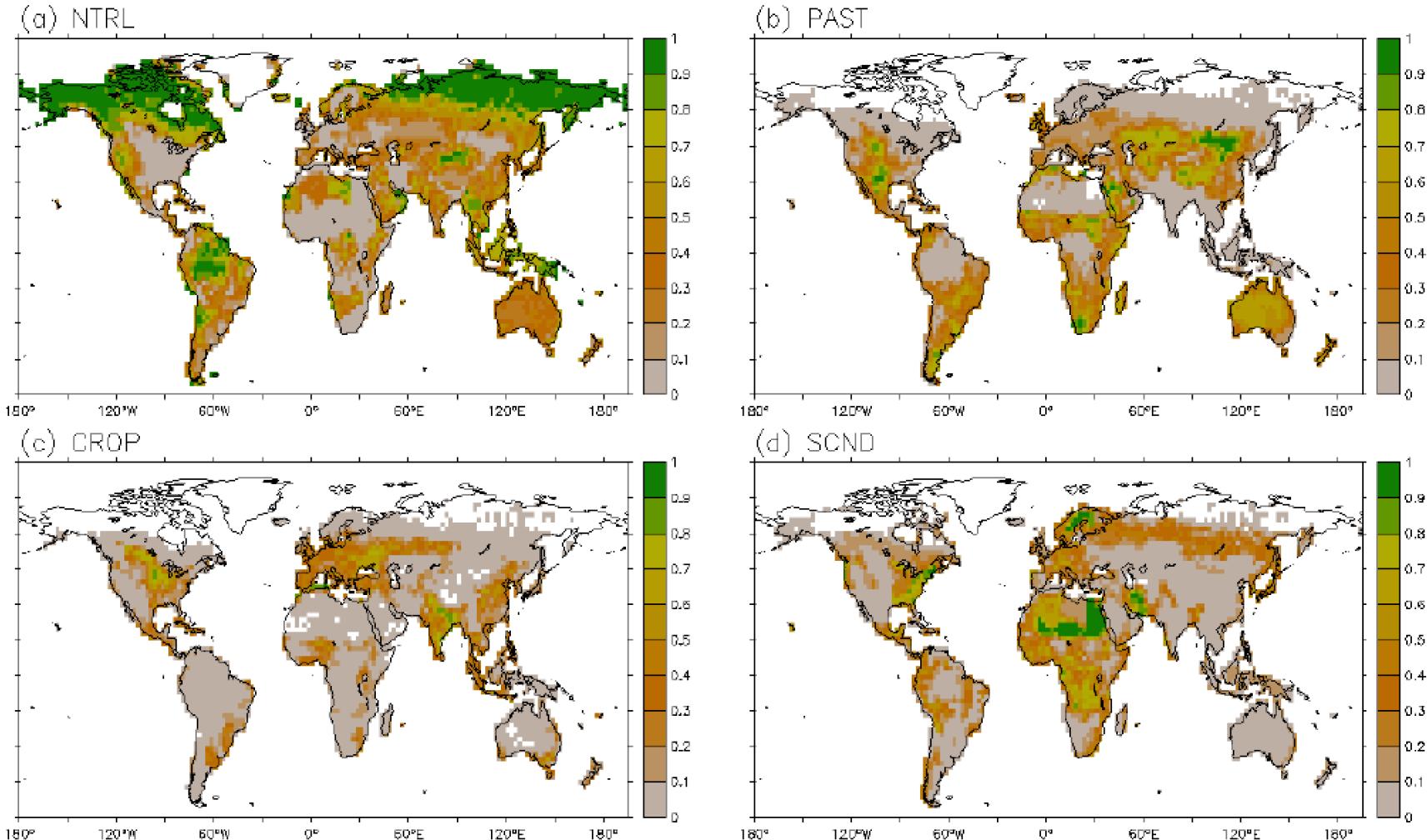
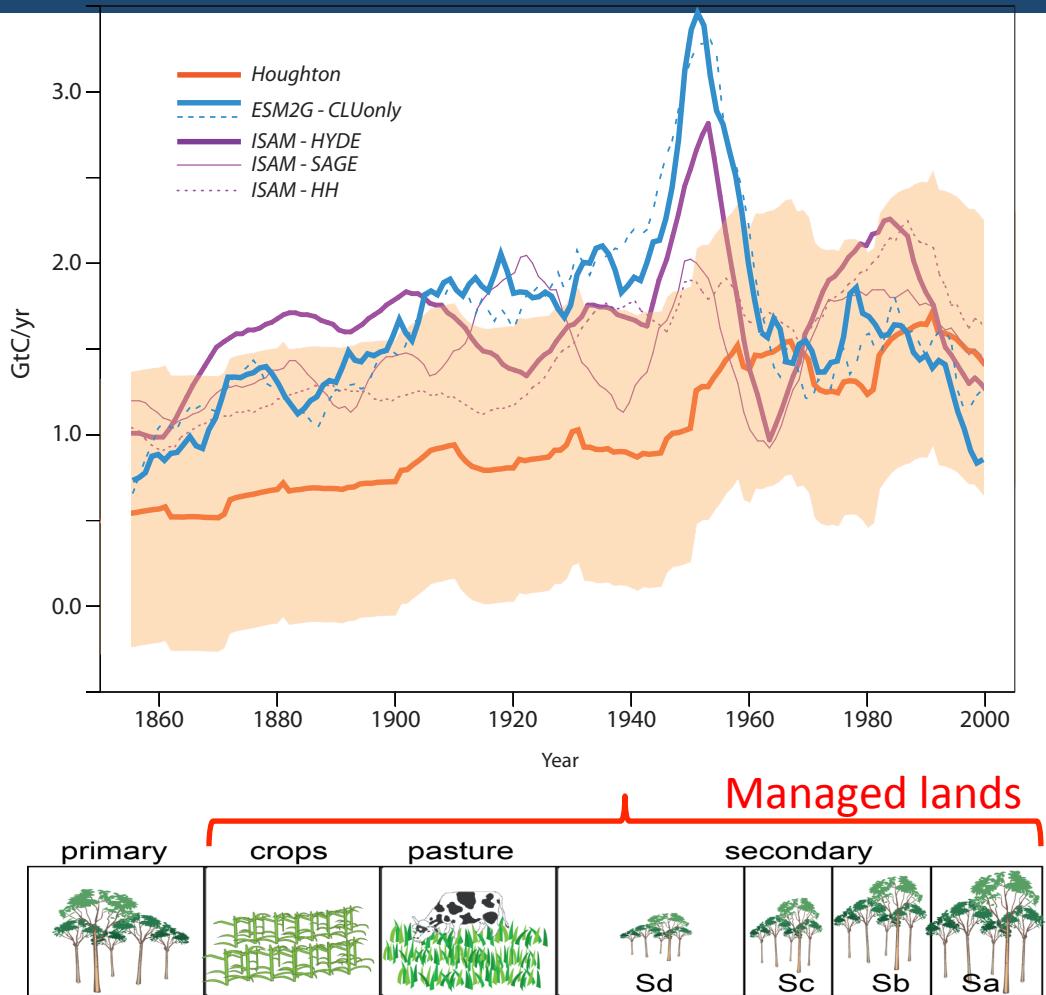


Figure 1. Fraction of grid box area covered by four land use types, averaged over 1986-2005 period. (a) natural (undisturbed) vegetation, (b) pasture, (c) cropland (d) secondary vegetation.

ESM2G land-use carbon emissions



Cumulative Land-Use Carbon (C) flux 1861-2005

GFDL ESM2G : 230 GtC
using book-keeping approach
1860 climate
constant atmospheric CO₂

ISAM: 210-230 GtC

Bookkeeping (Houghton):
160 Gt ± 50%

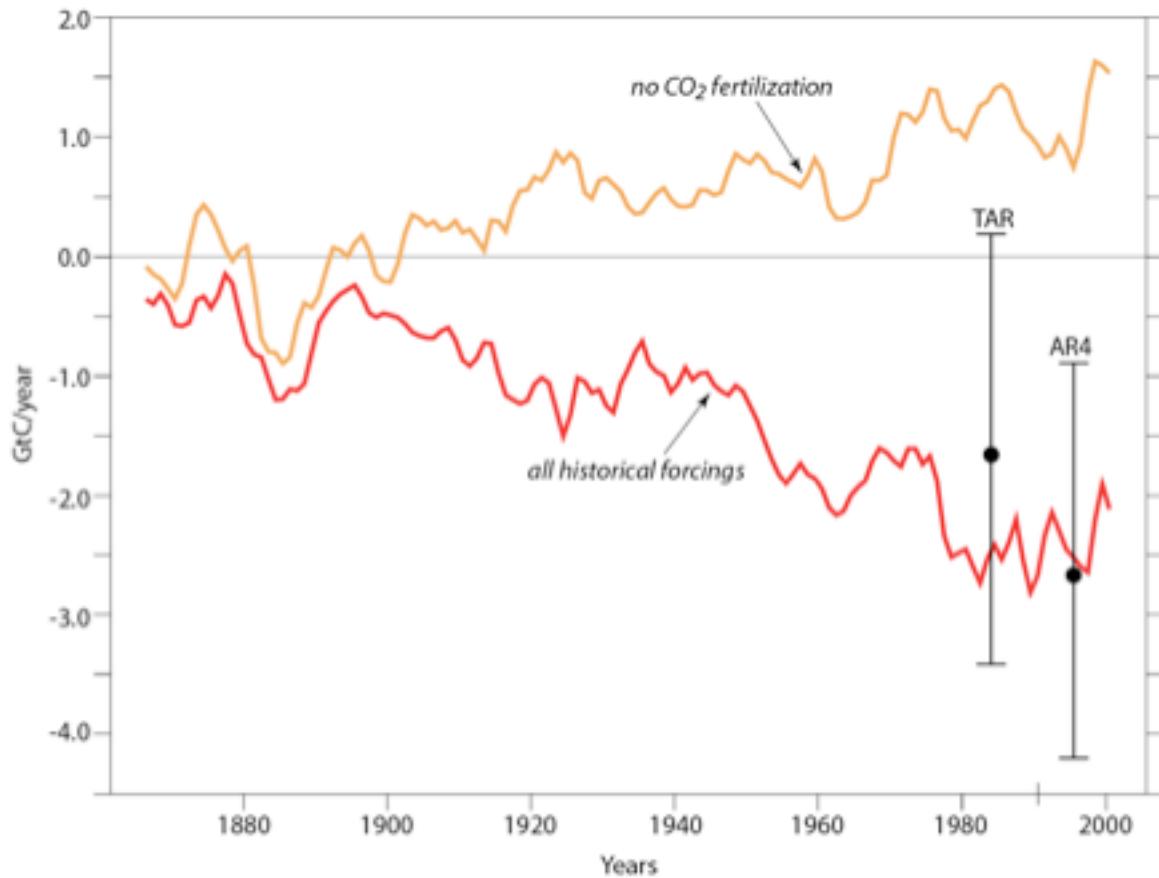
Larger Land-use Carbon source =>
Larger enhance land Carbon sink

Shevliakova et al, 2013

$$\text{Land Flux} = \text{Land Use C (Env=1860)} + \text{Residual C sinks}$$

Why is the enhanced vegetation uptake effect so big?

Residual carbon (C) sink = net land C flux – Land use C emissions



1861-2005 cumulative residual flux:

Historical:
~187 GtC sink

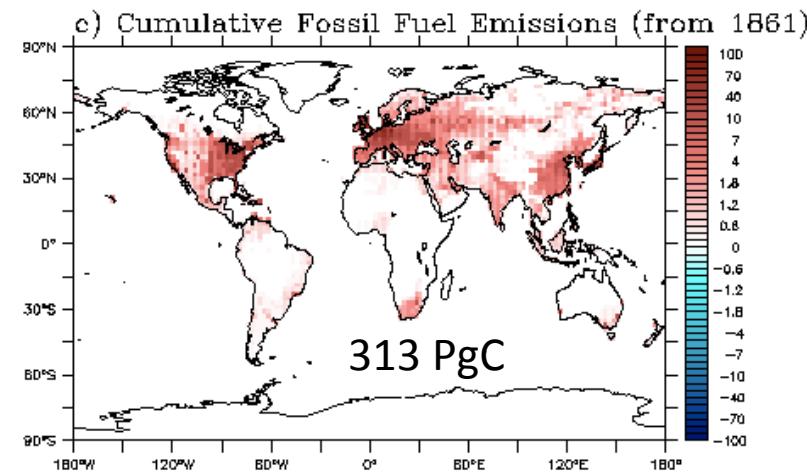
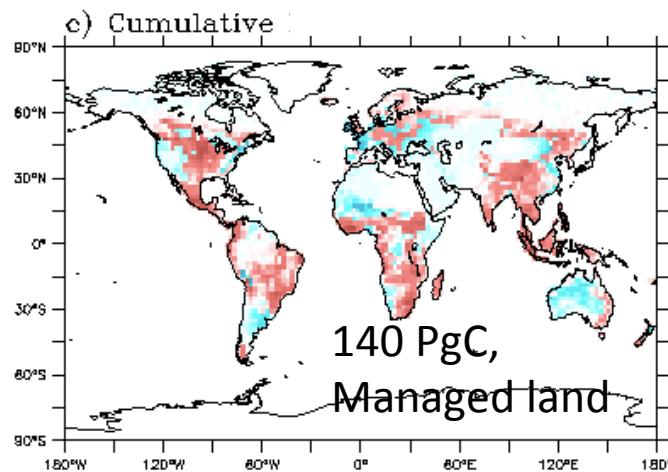
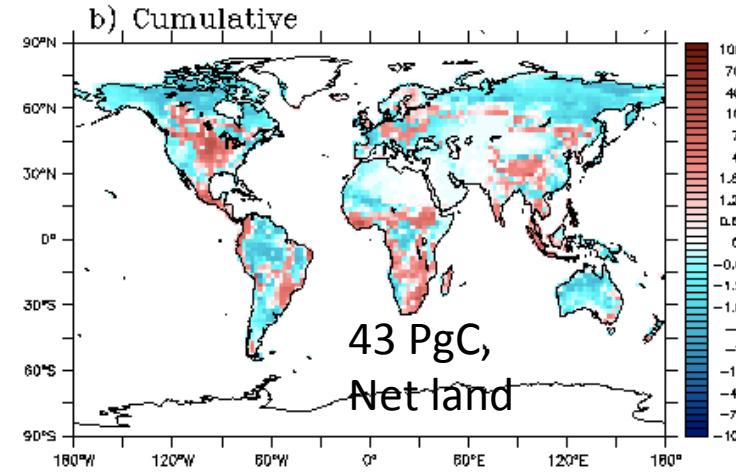
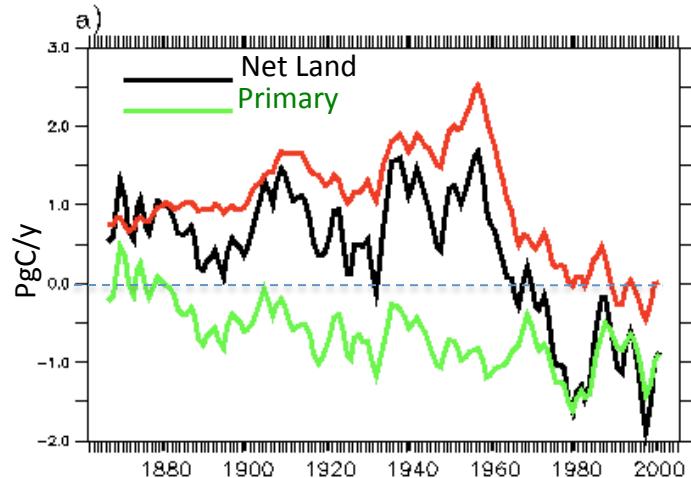
No sink enhancement:
~70 GtC source

Occurs on both unmanaged and managed lands!

Shevliakova et al, 2013

Historical land C flux on managed lands is a source; Land is sink from mid 20th-century

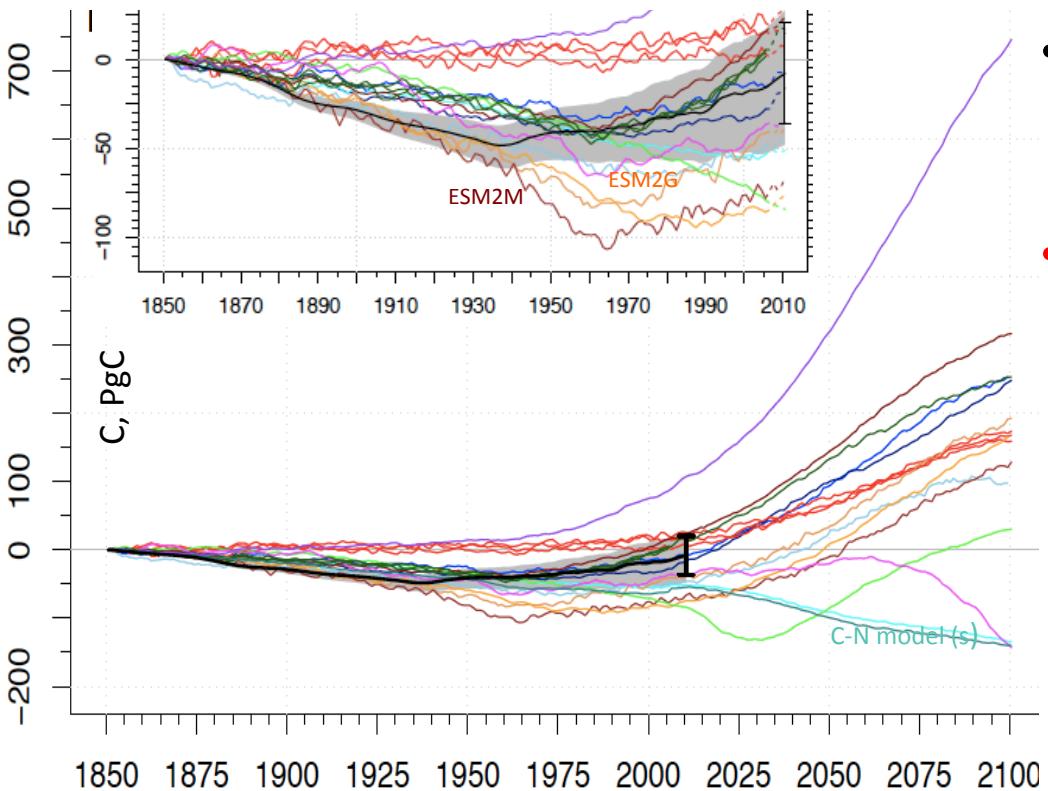
Land Flux = Land Flux Managed + Land Flux Unmanaged



ESM2G-E with all anthropogenic and natural forcing (*Shevliakova, in prep*)

A large spread in land C dynamics in CMIP5 ESMs

Land C Accumulation

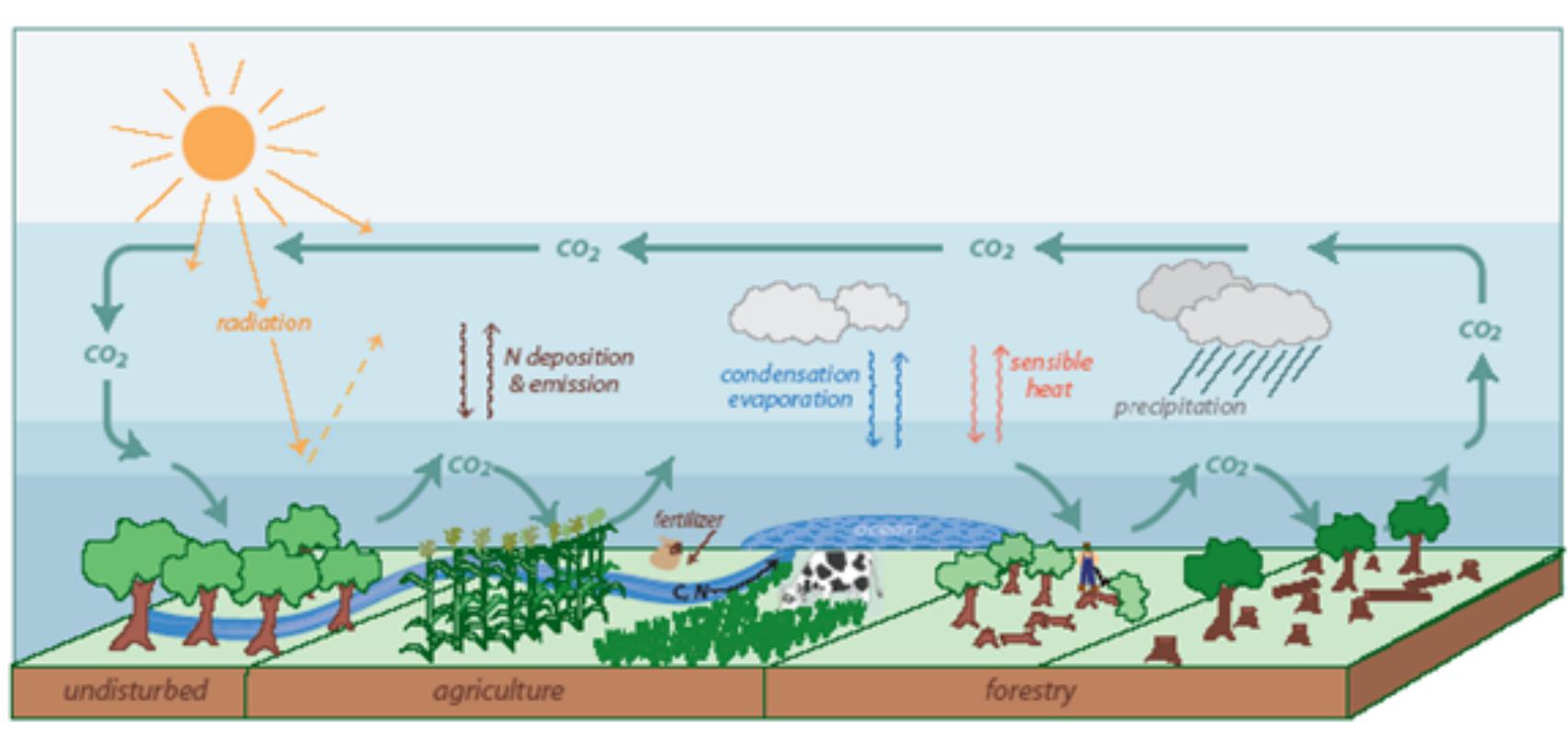


Hoffman et al. 2013

- Only 5 out 15 ESMs used prognostic biogeography
- All ESMs used Hurtt et al 2011 land use scenario but different implementations
- Large uncertainty in future land uptake
 - land-use change & management
 - nutrients limitation
 - ecosystems processes
 - climate change
 - interactions among the above

Challenges for land modeling

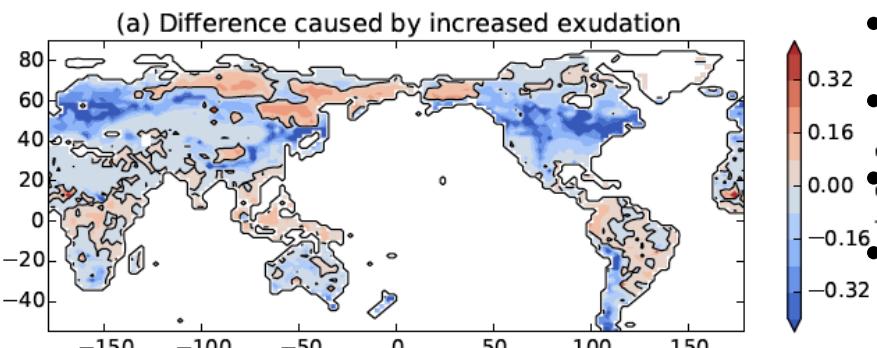
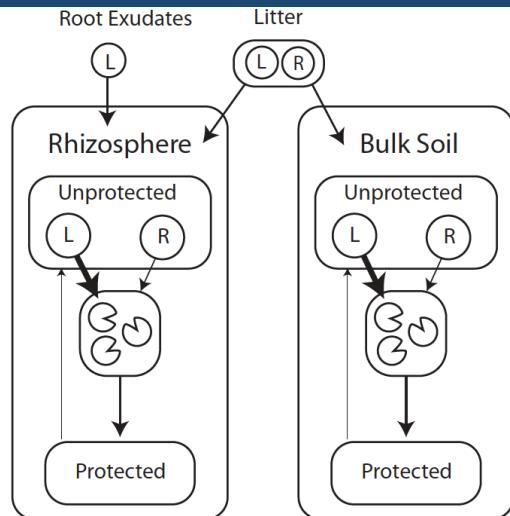
- Tight coupling between water, carbon and nutrient cycles
- Enormous biological diversity
- Uncertainty about underlying ecological mechanisms
- Surface heterogeneity



GFDL family of land models (LM#)

- Manabe (1969) – prognostic soil moisture and snow
- LM2 – multi-layer soil T, biome parameters (Milly & Shmakin, 2002)
- LM3 – new ecosystems and hydrology
 - Dynamic vegetation, land use, C cycle (Shevlakova et al. 2009)
 - Liquid and frozen H₂O, rivers & lakes, dynamic H₂O table (Milly et al 2014)
 - Coupled C-N in veg, soils & rivers (Gerber et al 2010, Lee et al 2014)
- **LM4 - ongoing developments for CM4/ESM4**
 - *Comprehensive* biogeochemistry: N, CH₄, BVOCs, P ...
 - Prognostic aerosols: dust, biomass burning, ...
 - Sub-grid hill-slope *heterogeneity*
 - New age-height vegetation succession model **LM3-PPA**
 - Land-use management: fertilizers, water quality,...
 - Model-data fusion

Soil Microbial Dynamics



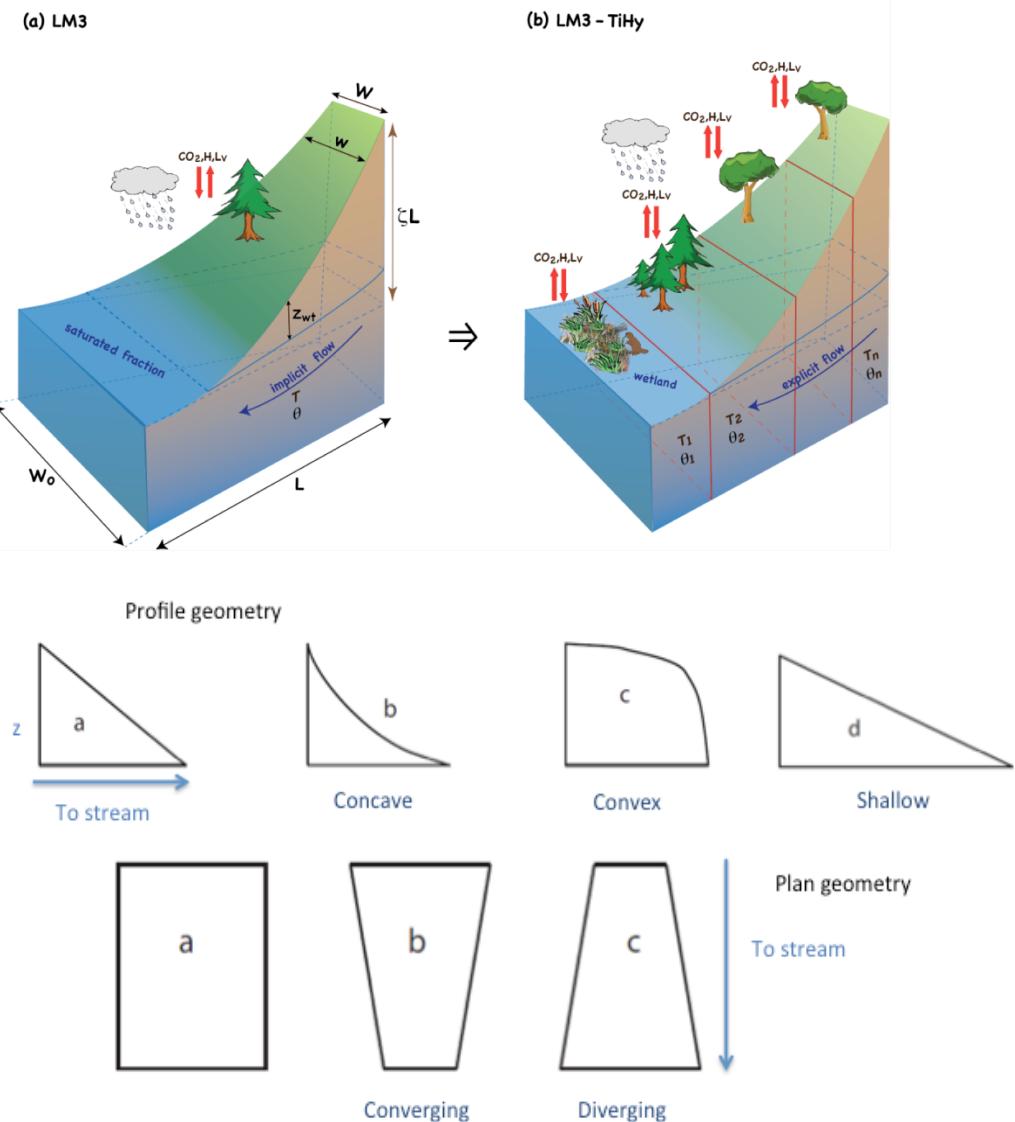
Sulman et al., 2015

Carbon, Organisms, Respiration, and Protection in the Soil Environment (LM3-CORPSE) model

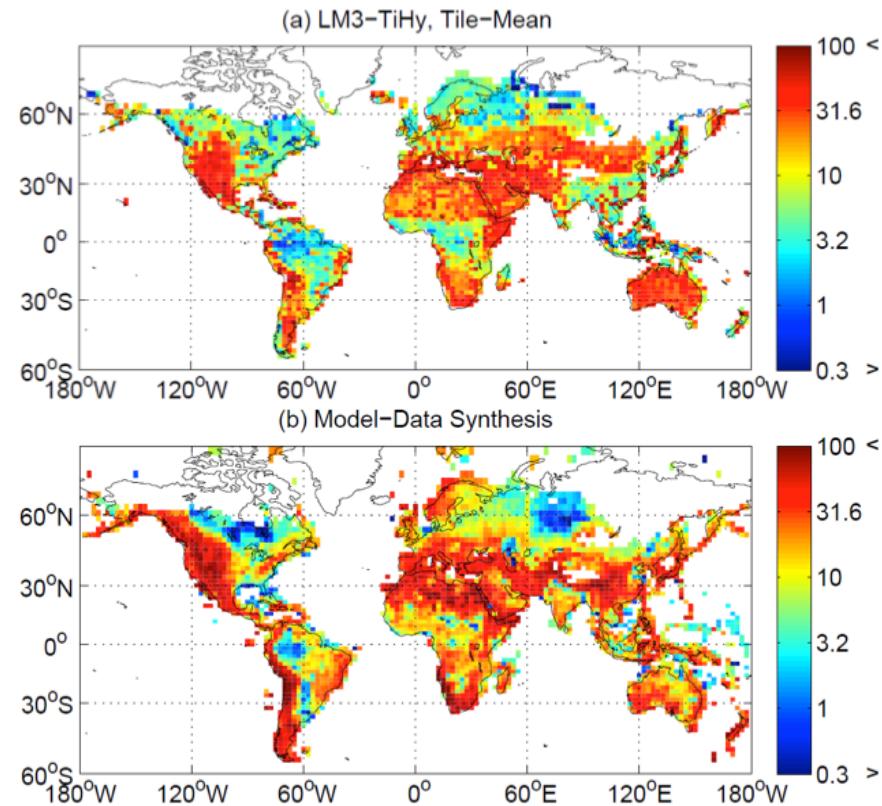
- Vertical structure
- Explicit above and below ground litter
- DOC leaching
- Dynamic microbial activity
- Protected carbon pools
- Root exudates
- Implemented in water-tiled version (LM3-TiHy)
- *Currently adding N*
- *P is next*

Key uncertainty: the sensitivity of soil Carbon to changing climate

Towards LM4: hill-slope tiling in LM3-TiHy



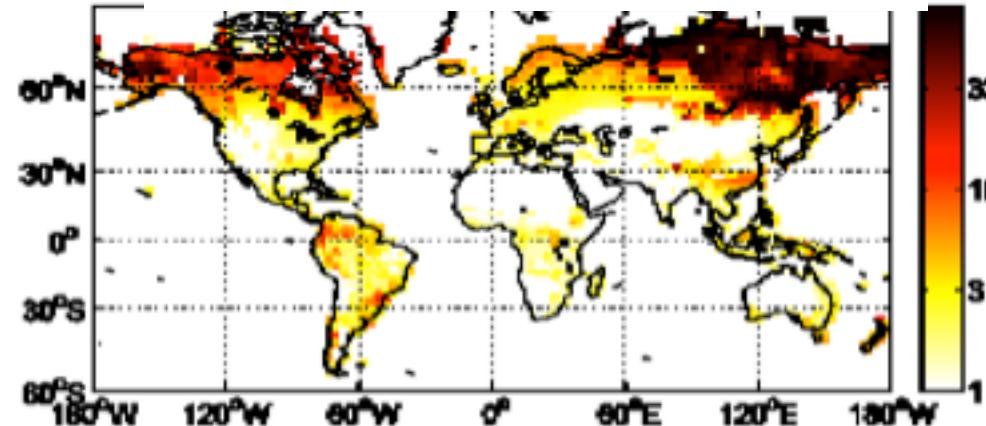
Water Table Depth



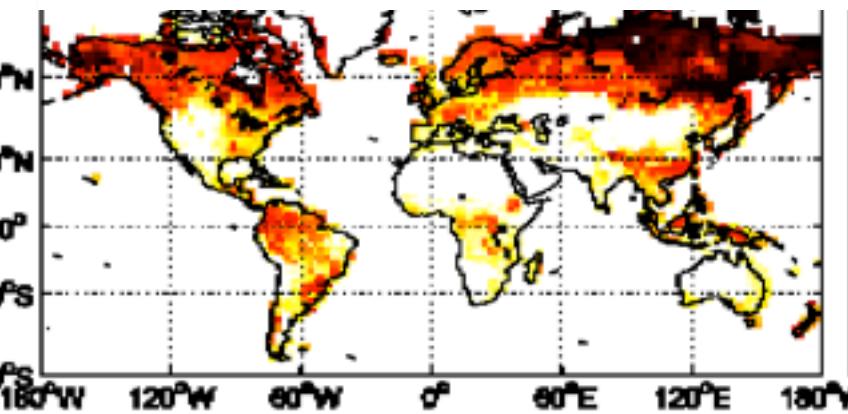
Subin et al. 2015, in rev

Effects of hydrological sub-grid heterogeneity on soil carbon

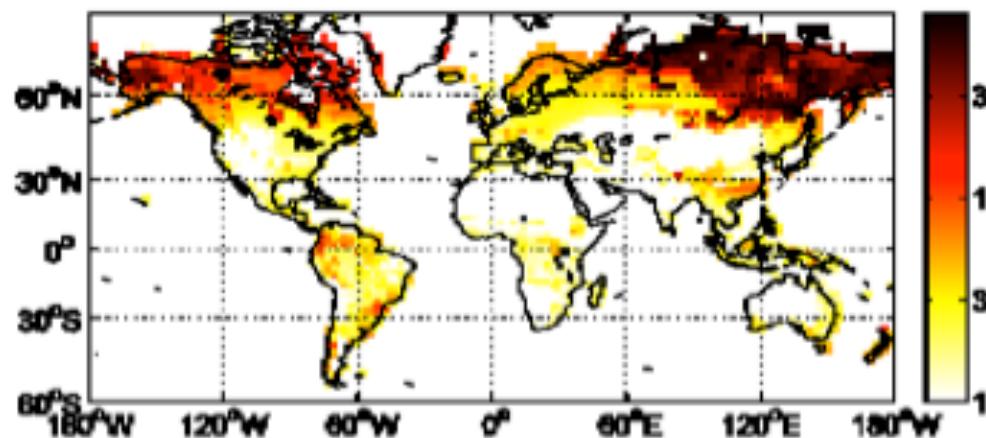
LM3 (857 Pg C)



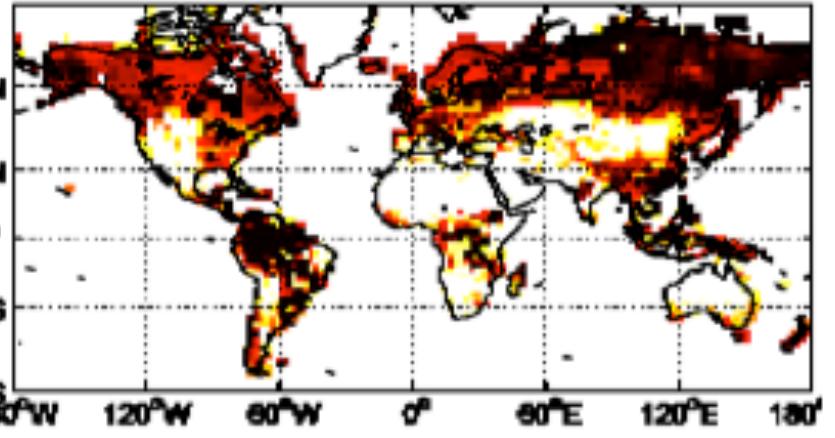
LM3-TiHy, Total (1120 Pg C)



LM3-TiHy, Upland 10% (77 Pg C)

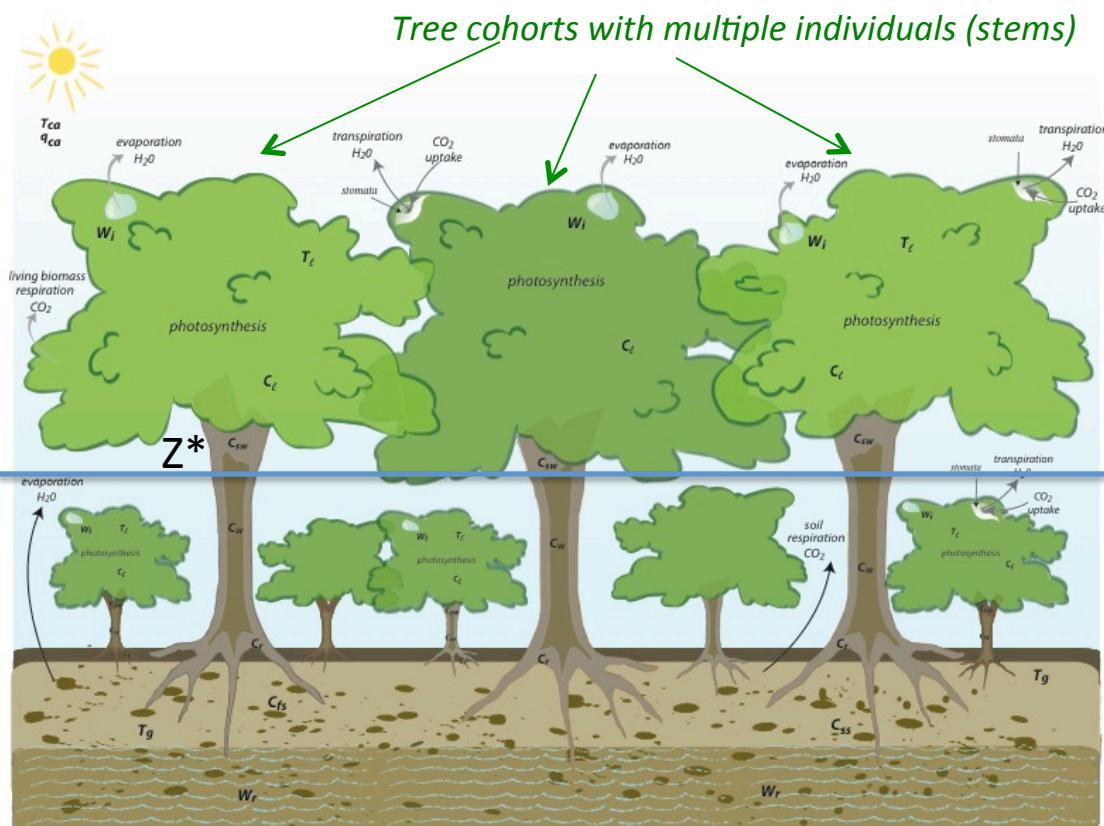


LM3-TiHy, Lowland 10% (261 Pg C)



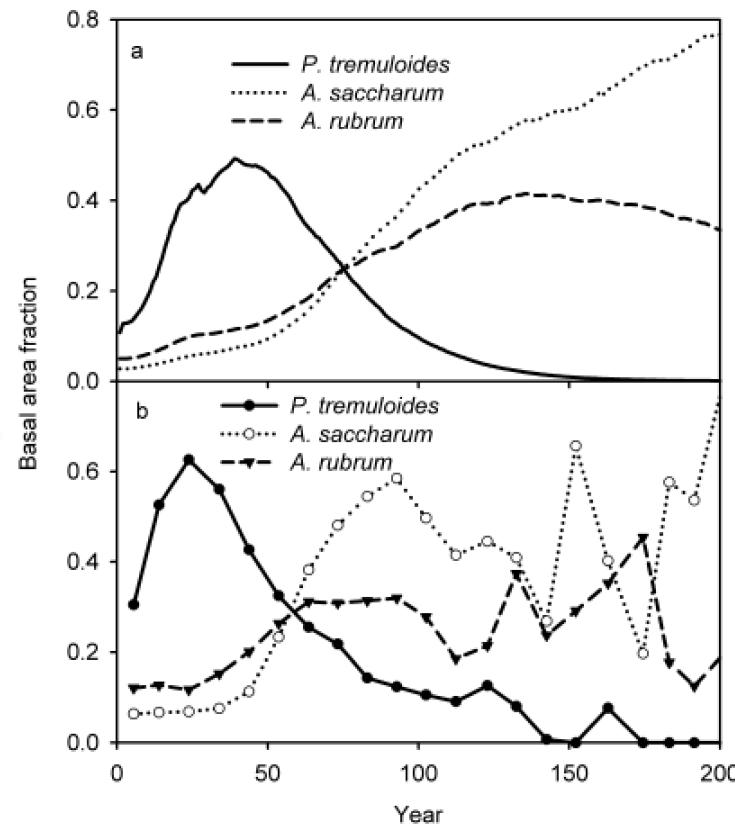
Lowland tiles contribute >3 times more soil carbon than upland tiles.

Perfect Plasticity Approximation (PPA) Vegetation Dynamics



- Challenges for global PPA
 - capturing plant diversity
 - phenology and mortality
 - evaluating succession

Willow Creek, WI



Weng et al., 2015
Strigul et al. 2008

Summary

- GFDL in collaboration with Princeton and USGS scientists developed successful terrestrial component of climate and ESMs models
- GFDL ESMs enables analyses of complex and dynamic interactions between land use and ecosystem processes on climate time-scales
- GFDL land modeling system allows to capture sub-grid heterogeneity in a unique dynamic tiling approach
- Two-way interactions between land biosphere and climate
- New physical, ecological and BGC approaches are developed and evaluated fro LM4
- Major challenges are still remaining
- Collaboration with broad scientific community is essential

Acknowledgements

- Princeton-GFDL CICS and PEI
- We are not a community model but we have a growing GFDL Land modeling community
- Land working group members and our collaborators:

GFDL: Ginoux, Krasting, Dunne, Phillips, Stock, Sentman, John

Princeton U: Malyshev, Sulman, Ward, Chaney, Smolander, Lee, Li, Rabin, Wolf, Anderegg, Weng, Paulot, Jaffe, Hedin, Pacala

USGS: Milly, Dunne

U. Florida: Lichstein, Gerber

UNH: Frolking

UMD: Hurt, Zhang

Purdue U: Smith, Dukes

Columbia U: Menge

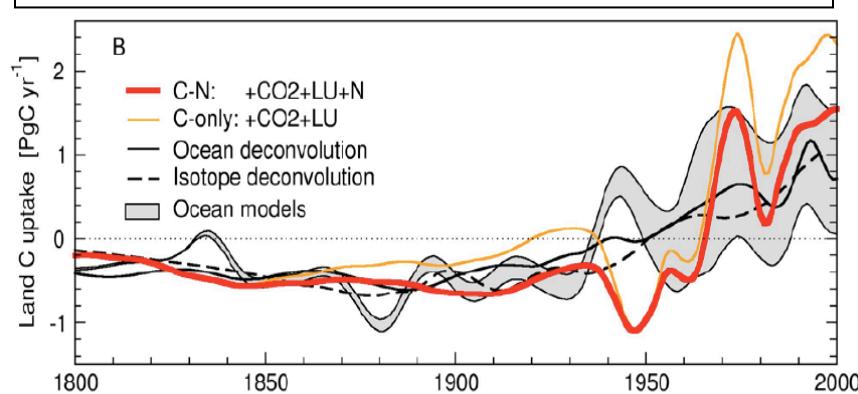
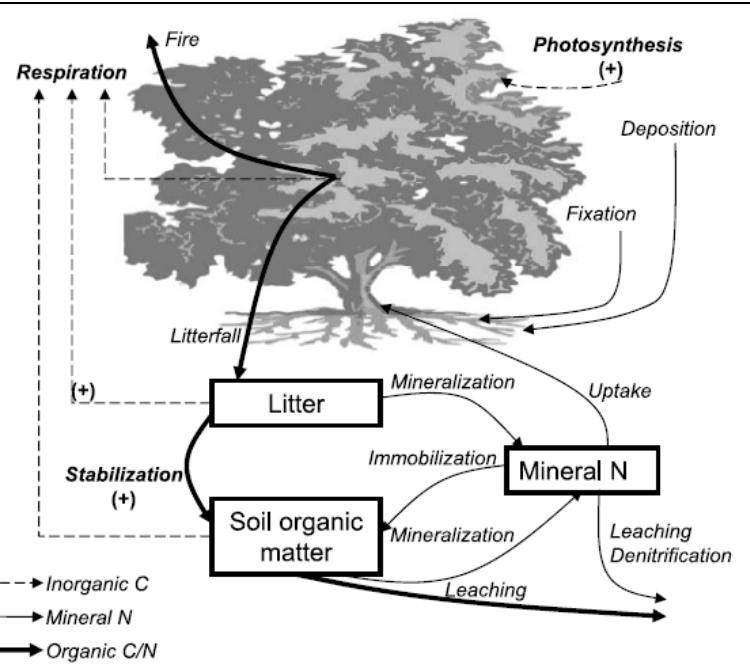
Duke: Bartlett, Porporato

Arizona U: Russel, Saleska, Pelletier

Smithsonian: Muller-Landau and Wright

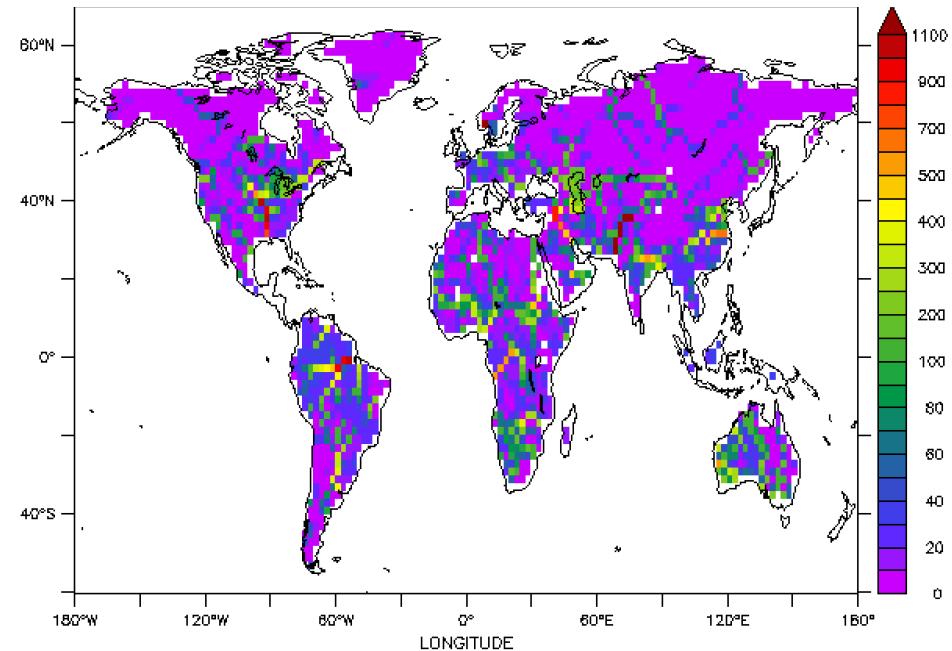
Stouffer

Towards closed Nr cycling in ESM-N



Gerber et al. 2010, 2013;

Dissolved Nitrogen River Load, Kt/yr



Lee et al. 2014, Lee et al., in prep

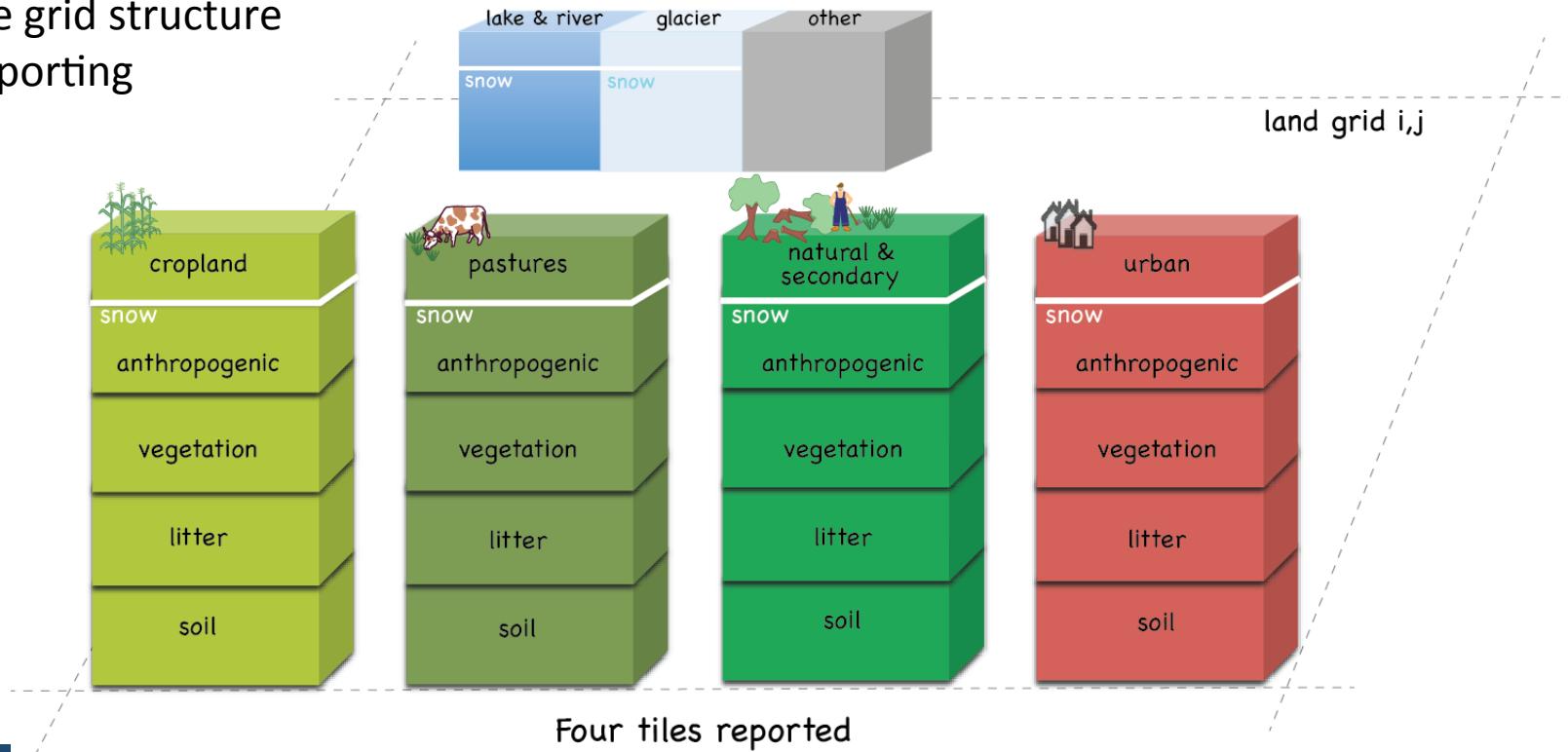
CMIP6 Land-Use MIP: introduces LU-centric reporting

<https://www2.cgd.ucar.edu/research/mips/lumip>

LUMIP | Land Use Model Intercomparison Project

We need to decide
on the grid structure
for reporting

Land Tiles



Overall Coupled Chemistry, Carbon-Climate and Ecosystems Achievements

- Improved understanding of processes determining biogeochemical distributions, change and impacts:
 - Led or co-authored over 200 scientific papers on atmospheric chemistry (>100), marine biogeochemistry (>40) and ecosystems (>40) and land ecosystems (>20) over the last 5 years
- Key contributor to CMIP5:
 - Reduced uncertainty in past and future chemistry-climate, ocean and land carbon uptake and biogeochemical feedbacks